Waste Management 84 (2019) 38–53

Contents lists available at ScienceDirect

Waste Management

journal homepage: www.elsevier.com/locate/wasman

Municipal solid waste (MSW): Strategies to improve salt affected soil sustainability: A review

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ARTICLE INFO

Article history:
Received 11 April 2018
Revised 20 September 2018
Accepted 12 November 2018

Keywords:
Municipal Solid Waste Compost (MSWC)
Salt-affected soils
Soil health
Environment
Soil properties

ABSTRACT

Salt-induced soil degradation is a serious threat to global agriculture which is responsible for diminished productivity of agro-ecosystems. Irrigation with poor quality water and indiscriminate use of chemical fertilizers to increase crop productivity creates salt accumulation in soil profile thereby reducing crop sustainability. High concentration of salts in soil inhibits plant growth due to low osmotic potential of the soil solution, ion toxicity and imbalance reduces nutrient uptake, crop yields. Low productivity of saline soils is not only due to salt toxicity or excess amounts of soluble salts but also lack of available mineral nutrients especially nitrogen, phosphorus, potassium and soil organic matter. Hence, sustainable management of salt-affected soils are paramount importance to meet the demands of food grain production for an ever-rising population in the world. Recently, municipal solid waste has gained importance as an organic amendment for restoring soil fertility and finally contributing to productivity of salt-affected soils. This paper compares extant waste generation, their properties and standards pertinent to municipal solid waste in different countries and explores the unique recent history in some countries that shows high environmental regard and rapid changes and also suggests policy experiencing from high environmental regard and rapid changes from other countries, so that policy makers can propose new or revise current municipal solid waste standards for salt affected soils. Municipal solid waste compost improves soil biological, physical and chemical properties because of high soil organic matter and lower concentration of pollutants. Therefore, the use of municipal solid waste in salt-affected soils could be an alternative to costly chemical amendments as well as reduce the reliance on chemical fertilizers for increasing productivity of salt-affected soil. The municipal solid wastes significantly improve crop yields. However, further long-term experimental investigations are needed to re-validate the application of municipal solid waste compost in improving physical, chemical and biological properties and to step up organic fertilization use in a wide range of both saline and sodic soils. In future, research should be directed to address these issues globally to minimise ecological disturbances and to set environmental standards, and evaluate the feasibility of the policies in different countries and their impact on socio-economic conditions of local people.

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https://doi.org/10.1016/j.wasman.2018.11.020
0956-053X/

Nomenclatures

Abbreviations/Symbols	Full form
MSW	Municipal Solid Waste
SOM	Soil Organic Matter
SOC	Soil Organic Carbon
N	nitrogen
P	phosphorus
K	potassium
MSWC	Municipal Solid Waste Compost
ESP	Exchangeable Sodium Percentage
SAR	Sodium Adsorption Ratio
ECe	Electrical Conductivity of saturation paste extract
CEC	Cation Exchange Capacity
DW	dry weight
GI	germination index
SG	seed germination
RE	relative root elongation
OECD	Organisation for Economic Co-operation and Development
GHG	greenhouse gases
qCO_2	microbial metabolic quotient
NI	nitrification index
Ca	calcium
Mg	magnesium
Na	sodium
Cl	chloride
C	carbon
C/N	carbon to nitrogen ratio
°	degree centigrade
ppm	parts per million
CO_2	carbon di oxide
%	per cent

1. Introduction

Rapid population increase, urbanization and industrial growth have led to severe waste management problems in the cities of developing countries like India. India generates 70 million ton of Municipal Solid Waste (MSW) per annum currently and expected to raise approximately 165 million ton by 2031 and by 2050 it could reach around 436 million ton (Planning Commission Report, 2014). The MSW compost is being used by farmers, researchers increasingly in salt affected soils as a soil conditioner as well as organic fertilizer (Wang et al., 2014). MSW in Indian mega-cities is mainly disposed in landfill by means of open dumping; however a small fraction is used for composting. Composting of MSW is considered as an important recycling tool since MSW would otherwise be land filled and lead to environmental and health issues (Cha-um and Kirdmanee, 2011). Apart from the environmental problems, there is a possibility that pollutants from city dumping sites may contaminate the underground water or may be absorbed by plants growing in the nearby agricultural fields and may thus create human and animal health problems (Eriksen et al., 1999).

Soil degradation is a major impediment to sustainable crop production in arid and semi-arid regions of the world. Soil salinity and nutrients deficiency are serious threat to global agriculture (Zhang et al., 2007). Additionally, the increase in the generation of MSW, there is a need to make available more areas for the disposal of wastes in landfill. Therefore, other alternatives of wastes disposal should be studied and evaluates, such as: incineration, gasification and pyrolysis. These thermochemical conversion options would be extremely useful and would corroborate with the reduction of the total volume of wastes (Lakhdar et al., 2011). In addition, the Soil Organic Matter (SOM) fraction of the MSW could be extracted for production of compost. The compost improves soil biological, physical and chemical properties because of the higher SOM (Násner et al., 2017). Approximately 20% of the world's cultivated area and around 50% of the irrigated croplands are affected by soil salinity (Zhu, 2001). Consequently, the affected areas are predicted to be increased with the use of poor quality water and the intensive application of chemical fertilizers (Wong et al., 2005). However, inappropriate irrigation and drainage systems have resulted in rising groundwater levels, which have the potential to trigger salt accumulation in the soil profile and have a negative effect on crop production (Qadir et al., 2009). In addition, limited precipitation, high evaporation and inadequate soil and water management have contributed to an increase in salinity (Leme et al., 2014). The alternate strategies might be (i) vegetative bioremediation- a plant assisted reclamation approach-relies on growing appropriate plant species that can tolerate ambient soil salinity and sodicity levels during reclamation of salt-affected soils. A variety of plant species of agricultural significance have been found to be effective in sustainable reclamation of calcareous and moderately sodic and saline-sodic soils; (ii) second strategy fosters dedicating soils to crop production systems where saline and/or sodic waters predominate and their disposal options are limited (Qadir and Oster, 2004). Production systems based on salt tolerant plant species using drainage waters may be sustainable with the potential of transforming such waters from an environmental burden into an economic asset (Luz et al., 2015). Such a strategy would encourage the disposal of drainage waters within the irrigated regions where they are generated rather than exporting these waters to other regions via discharge into main irrigation canals, local streams, or rivers. Being economically and environmentally sustainable, these strategies could be the key to future agricultural and economic growth and social wealth in regions where salt affected soils exist and where saline-sodic drainage waters are generated (Qadir and Oster, 2004). It is well known that saline soils are deficient in Soil Organic Carbon (SOC), Nitrogen (N), Phosphorus (P) and Potassium (K) (Meena et al., 2016a); antagonism of sodium leads to deficiency of K and Calcium (Ca) (Marschner, 2012). Excess salt concentration (Na^+) adversely not affects only the soil physico-chemical properties, especially the structural stability and bulk density, which strongly compromise with crop productivity but enhances the dispersion of clay, thus decreasing soil permeability also. As per Centre Pollution Control Board, India Ca in the range of 40–100 ppm, and Magnesium (Mg) in the range of 30 to 50 ppm are considered desirable for irrigation water. Acceptable levels of Sodium (Na) and Chloride (Cl) for ornamentals are <50 ppm and 140 ppm, respectively, however higher levels may be tolerated depending on crop sensitivity. Permissible limit of Sodium Adsorption Ratio (SAR) and boron (in ppm) is 26 and 2 for irrigation, respectively. Sodicity causes structural problems in soils created by physical processes such as slaking, swelling as well as conditions that may cause surface crusting and hard setting (Quirk, 2001). Such problems affect water and air movement, plant-available water holding capacity, root penetration, runoff, erosion and tillage and sowing operations; subsequently, imbalances in plant-available nutrients in both saline and sodic soils affect plant growth (Meena et al., 2016b).

Establishment of sustainable techniques for managing salt-affected soils and increasing crop productivity are needs of the hour. The restoration of microbial activity is a basic step for reclamation of saline soil (Meena et al., 2016a) because microbes have potential to reinstate the fertility of degraded land through various processes. These microorganisms increase the nutrient bioavailability through nitrogen-fixation and mobilizations of key nutrients (phosphorus, potassium and iron) to the crop plants while remediate soil structure by improving its aggregation and stability (Qadir and Schubert, 2002). Though, success rate of such processes under field conditions depends on their antagonistic or synergistic interaction with indigenous microbes or their inoculation with organic fertilizers. Maintenance of adequate soil physical and chemical properties of saline soil may be achieved by using good quality water, rational use of chemical fertilizers, integrated use of organic amendments and appropriate cultural practices (Grattan and Oster 2003). Of late, many technologies has been developed for reclamation of salt-affected soil, as physical amelioration (deep ploughing, sub-soiling, sanding, and profile inversion), chemical amelioration (amending of soil with various reagents: gypsum, calcium chloride, and limestone) and electro-reclamation (treatment with electric current) (Raychev et al., 2001). Alternatively, salt tolerant plant species can be only cost effective means of getting higher crop yield (Abdelly et al., 2006). Several organic amendments, such as MSW, manures, and composts have been investigated for their positive role in soil remediation (Meena et al., 2016b), and they have been reported to improve soil sustainability. Application of organic amendments improves physical, chemical and biological properties of salt-affected soils, and SOM, eventually. Meena et al. (2016a) noted that application of organic amendments increased nutrient concentrations especially NPK, organic carbon, microbial biomass and enzymatic activities in salt-affected soils. The MSW Compost (MSWC) has two beneficial effects on reclamation of saline soil: improvement of soil structure and permeability thus enhancing salt leaching, reducing surface evaporation and inhibition of salt accumulation in surface soils, and release of CO_2 during respiration and decomposition of compost (Raychev et al., 2001). However, potential ecological and health risks may arise due to nutrient transport to ecologically sensitive receptors and accumulation of trace elements in the soil profile and their entry in food chain (Smith, 2009). These issues should be carefully addressed in order to mitigate the environmental impacts and optimize compost use in agriculture. For these reasons, many states/countries have developed specific guidelines regulating its safe use, although they are still under discussion (Barral and Paradelo, 2011).

The study of environmental standards from different countries applicable to MSW is not widely published, much less those for MSWC. Previous studies have addressed the effect of MSWC/MSW on soil properties, crop yield and environmental issues separately and the studies are also region specific. There has been a lack of suggestions for management of ill effects of MSW. Insufficiency of holistic knowledge on MSWC quality and maturity also has generated confusions among readers; also information regarding these issues on a global basis is scanty. This paper compares extant waste generation, their properties and standards pertinent to MSW in different countries and explores the unique recent history in some countries that shows high environmental regard and rapid changes and also suggests policy experiencing from high environmental regard and rapid changes from other countries, so that policy makers can propose new or revise current MSW standards for salt affected soils.

The purpose of this review paper is to investigate the effects of MSWC as an ameliorant and soil conditioner to alleviate the negative effect of salt-affected soils. In future, research should be directed to address these issues globally to minimise ecological disturbances and to set environmental standards, and evaluate the feasibility of the policies in different countries and their impact on socio-economic conditions of local people.

2. Extent and distribution of salt-affected soils

Salt-affected soils are distributed in 120 countries covering around 953 Mha and reduced productivity to 7–8% at the global scale (Yadav, 2003). Sodic soils are dominant (around 50%) with largest area in Australia (Table 1) while sizeable area (around 20%) is saline in drylands of Asia and Pacific and waterlogged and secondary salinized (around 40 Mha) in irrigated regions (Ghassemi and Nix, 1995). In India, total salt-affected area is around 6.73 Mha, out of which 3.77 Mha is sodic and 2.95 Mha is saline (Tripathi, 2011). Table 2 reports the potential area of salt-affected soils in all over the world, which should be brought under cultivation to meet out the demand of food grain for burgeoning population.

Globally, around 954 Mha chemically degraded soils are distributed in nine sub-continents, largest area is located in Australia (around 54%) followed by North and Central Asia (around 22%), South America (around 13%), South Asia (around 9%) and Africa (8.4%) (Szabolcs, 1989). In India, total land degradation around 121 Mha eroded due to erosion (water and wind erosion), salt-affected, acidic soils and physically degraded (mining, industrial waste and water logging) covered around 95, 6.74, 17.94 and

Table 1
Salt-affected soils in all over the world.

Name of country	Salt-affected area	References
Australia	30% (total area)	Rengasamy (2005)
Thailand	30% (total area)	Yuvaniyama (2001)
Egypt	9.1% (total area)	Mashali et al. (2005)
Hungry	10% (total area)	Varallyay (1992)
Iran	28% (irrigated land)	Khel (2006)
Kenya	14.4% (total area)	Mashali et al. (2005)
Nigeria	20% (irrigated land)	FAO (2000)
Russia	21% (irrigated land)	Dobrovol'skii, G.V., Stasyuk, N.V. (2008)
Syria	40% (irrigated land)	FAO (2000)
Tunisia	30% (total area)	Mashali et al. (2005)
USA	25–30% (irrigated land)	Wichelns, (1999)
India	4.2% (total arable land)	Sharma et al. (2015)
China	4.88% (total available land)	Wang et al. (2011)

1.07 Mha, respectively (NAAS, 2012). The area statistics disclosed around 80% salt-affected soils are associated with arable cropping, around 18% co-existed with water erosion and 2% is located in the forest covered areas. These soils currently occupying 2% of the geographical area of the country and constitute 4.2% of the arable land area (Sharma et al., 2015). Globally, salt affected areas on average cover around 20% of the world's irrigated lands whereas in arid and semiarid countries it increases to more than 30% (Asfwa et al., 2016). Salt-affected soils covering more than 120 countries with different extents, nature and properties led to 7% to 8% reduction of the productive capacity of the land. In India, the salt affected area in the country was 7.42 Mha (soil salinity plus alkalinity). Hence Indian farming community faces a great challenge of increasing the food grain production to feed the ever growing population (Asfaw et al., 2016).

3. Production potential of municipal solid waste

The MSW management has become an issue of developing world (Tacoli, 2012). As the world hurtles toward its urban future, the amount of MSW, one of the most important by-products of an urban lifestyle, is growing even faster than the rate of urbanization (World Bank, 2012). The World Bank study revealed around 70% global increases in urban MSW with developing countries facing the greatest challenges. The projected rise in the amount of MSW, from 1.3 billion tonnes per year today to 2.2 billion tonnes per year by 2025, and is predicted to be raising the annual global costs from $205 billion to $375 billion (World Bank, 2012). An attempt to summarise the MSW generation per capita region wise, indicating the lower boundary and upper boundary for each region, as well as average kg per capita per day of waste generated within each region has been made (Fig. 1). Future projections of MSW generation by region wise are shown in Table 3. The composition of waste composition is categorized as organic, paper, plastic, glass, metals, and other. These categories can be further refined, however, these six categories are usually sufficient for management of solid waste. Table 4 indicates the different types of waste and their sources. The MSW form the East Asia and the Pacific Region has the highest fraction of organic waste (around 62%) compared to OECD countries (Organisation for Economic Co-operation and Development), which have the least (27%) of these. The amount of paper, glass, and metals found in the MSW stream are the highest in OECD countries (around 32, 7, and 6%, respectively) and lowest in the South Asia Region (4% for paper and 1% for both glass and metals). However, in developed countries MSW have few organic materials making it difficult to use them for composting or organic fertilizer, and makes other alternatives to be used for their final destination, for example: recovery by means of landfill disposal and use of biogas, incineration, gasification, pyrolysis, etc.

Table 2
Effects of various organic matter inputs under soil salinity conditions (essential data).

Organic Materials	Soil salinity/ salt levels	Effects	Reference
Cotton gin crushed compost and poultry manure	ESP 15.7 EC 9 mS/cm pH 8.0	Improving soil structure, reducing (by 50%) the ESP and increasing different enzyme activities	Tejada et al. (2006)
Mixture of green waste compost, sedge peat and furfural residue	ESP 15.8 EC 3.69 mS/cm pH 7.75	Decreasing bulk density, EC, and ESP and increasing total porosity and organic carbon. The combination of amendments had substantial potential for ameliorating saline soils, working better than each amendment alone	Wang et al. (2014)
Pig manure + rice straw	Total salts 3.3 g/kg pH 8.86	The incorporation of organic manure into the soil significantly increased soil alkaline phosphatase activity and soil respiration rate	Liang et al. (2003)
Green manure mixed + farmyard manure	Salt 1–2% EC 8.5–20.4 mS/cm pH 4.58–4.79	The OM application in paddy fields could effectively alleviate the problem of soil salinity, also resulting in yield improvement	Cha-um and Kirdmanee (2011)
Cassava-industrial waste compost and vermicompost	EC 4.26 mS/cm pH 7.30	Compost and vermicompost amendments decreased electrical conductivity, improved CEC, soil organic carbon, total nitrogen and extractable phosphorus	Oo et al. (2013)
Compost produced from by-products of the olive oil industry and poultry manure	EC 1.85 mS/cm pH 7.7	Increasing soluble and exchangeable-K$^+$ (thus limiting the entry of Na$^+$ into the exchange complex) as well as CEC.	Walker and Bernal (2008)
Farmyard manure + saline water (EC 2.25 mS/cm)	EC 4.8–6.3 mS/cm	Improvement of infiltration rate by about 89%, and decreasing soil sodicity by 41.3%. Decreasing soil bulk density, allowing an enhancement of soil porosity	Kahlown and Azam (2003)
Compost (animal wastes + plant residues)	ESP 34–37 EC 4.03–5.11 mS/cm pH 8.62–8.75	Decreasing EC and SAR. Organic amendments co-applied with chemical amendments seemed to have a high value for reducing soil pH, soil salinity and sodicity	Mahdy (2011)
Municipal wastewater	EC 60 mS/cm pH 7.48	Decreasing soil pH and bulk density, while increasing EC and OM content of soil.	Mojiri (2011)
Farm yard manure	EC 3.7–5.0 mS/cm pH 8.69–9.18	Gypsum + sulfuric acid + Farm yard manure decreased bulk density but increased the porosity, void ratio, water permeability and hydraulic conductivity	Hussain et al. (2001)
MSWC and sewage sludge	EC 75 mS/cm pH 8.2	13.3 g/kg of compost significantly improved soil physical-chemical properties, especially C and N contents. Enzyme activities were substantially promoted in presence of both amendments	Lakhdar et al. (2010)

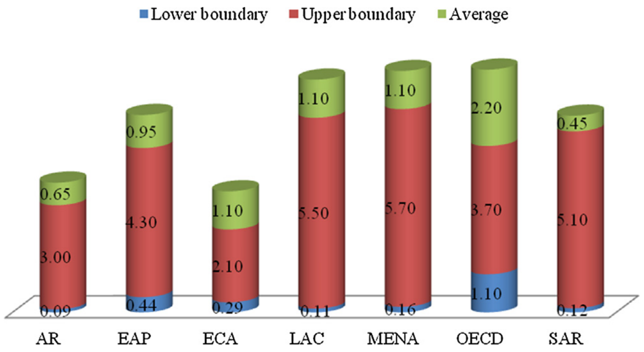

Fig. 1. Current Waste Generation Per capita (kg/capita/day) by region wise {AR (Africa region); EAP (East Asia and pacific region); ECA (Europe and Central Asia region); LAC (Latin America and the Caribbean); MENA (Middle East and North Africa region); OECD (Organization for Economic Co-operation and Development) and SAR (South Asia region)}

MSWCs are often characterized by increased contents of trace elements and heavy metals, due to the inadequate separation of biodegradable fractions from non-degradable or inert materials (Smith, 2009) and published studies have shown increased accumulation of Cu, Pb and Zn in plant tissues (Paradelo et al., 2011). However, the accumulation of trace elements in plant tissues depends on their availability which in turn is affected by composting method, soil properties and plant species/cultivar. Additional issues that should be considered include increases in soil electrical conductivity and changes in pH and nitrogen availability (Hargreaves et al., 2008).

Indeed, excessive application of low quality composts can result in an accumulation of pollutants in the soil, which affects the metabolism of living microbes (Lin et al., 2007). Therefore, non-conventional techniques of soil remediation uses, especially non-selective collection of MSW, could induce an accumulation of heavy metals in plants as well as soil, leading to a decrease in their biomass and chlorophyll contents (Sinha and Gupta, 2005) and impairment of the photosynthetic efficiency. Therefore, for sustainable management of salt-affected soils through addition of MSWC stringent quality of waste materials has to be applied in soil for achieving the desired beneficial effect for long-term (Achiba et al., 2009). Environmental issues are often neglected during MSW application, which leads to serious human health problem. Hence, environmental regulations and standards are important as they maintain balance among competing resources and help protect human health and the environment. Proper MSW management is crucial for urban public health. However, the reuse of MSW in soil must be regulated because they may expose the environment to toxic heavy metal elements.

Table 4
Types of waste and sources of generation.

Types	Sources
Organic	Food scraps, yard (leaves, grass, brush) waste, wood, process residues
Paper	Paper scraps, cardboard, newspapers, magazines, bags, boxes, wrapping paper, telephone books, shredded paper, paper beverage cups. Strictly speaking paper is organic but unless it is contaminated by food residue, paper is not classified as organic.
Plastic	Bottles, packaging, containers, bags, lids, cups
Glass	Bottles, broken glassware, light bulbs, colored glass
Metal	Cans, foil, tins, non-hazardous aerosol cans, appliances (white goods), railings, bicycles
Others	Textiles, leather, rubber, multi-laminates, e-waste, appliances, ash, other inert materials

3.1. Effect of municipal solid waste on environmental and human health

The health and environmental implications associated with garbage disposal are mounting in urgency, particularly in developing countries. The establishment of sustainable MSW management practices implies minimizing their environmental losses of pollutant gases associated with climate change due to emission of greenhouse gases (GHGs) and ecosystems acidification through ammonia (NH_3) evolution. Although a number of management strategies for solid waste management have been investigated to quantify nitrogen (N) and carbon (C) losses in relation to varied environmental and operational conditions, their overall effect is still uncertain (Pardo et al., 2015). Urbanization, improving living standards and population growth combined to speed up the rate of generation of MSW causing its management to be the main environmental problem affecting urban centres globally. Open-burning of waste is particularly discouraged because of the severe air pollution associated with low-temperature combustion (World Bank, 2012). There are potential risks to environment and health from improper handling of solid wastes. Direct health risks concern mainly the workers in this field, who need to be protected, as far as possible, from contact with wastes. There are also specific risks in handling wastes from hospitals and clinics. For the general public, the main risks to health are indirect and arise from the breeding of disease vectors, primarily flies and rats (Royal Commission on Environmental Pollution, 1984). Uncontrolled hazardous wastes from industries mixing up with municipal wastes create potential risks to human health (Alam and Ahmade, 2013). There is specific danger of concentration of heavy metals in the food chain, a problem that illustrates the relationship between MSW and liquid industrial effluents containing heavy metals discharged to a drainage/sewerage system and /or open dumping sites for MSW and the wastes discharged thereby maintains a vicious cycle including

Table 3
Waste Generation projections by 2025 of different regions.

Regions*	Current available data			Prediction for 2025			
	Total urban Population (millions)	Urban MSW generation		Projected population		Projected Waste	
		kg/capita/day	Total (ton/day)	Total population (millions)	Urban population (millions)	kg/capita/day	Total (ton/day)
AFR	260	0.65	169,119	1152	518	0.85	441,840
EAP	277	0.95	738,958	2124	1229	1.50	1,865,379
ECA	227	1.10	254,389	339	239	1.50	354,810
LAC	399	1.10	437,545	681	466	1.60	728,392
MENA	162	1.10	173,545	379	257	1.43	369,320
OECD	729	2.20	1,566,286	1031	842	2.10	1,742,417
SAR	426	0.45	192,410	1938	734	0.77	567,545
Total	2480	7.55	3,532,252	7644	4285	9.75	6,069,703

* **AFR**: Africa, **EAP**: East Asia and Pacific, **ECA**: Europe and Central Asia, **LAC**: Latin America and Caribbean, **MENA**: Middle East and North Africa, **OECD**: Organisation for Economic Co-operation and Development, **SAR**: South Asia Region

these some other types of problem are as follows (Royal Commission of Environment pollution, 1984) (a) chemical poisoning through chemical inhalation, (b) uncollected waste can obstruct the storm water runoff resulting in flood, (c) low birth weight, (d) cancer, (e) congenital malformations, (f) neurological disease, (g) nausea and vomiting, (h) mercury toxicity from eating fish with high levels of mercury, (i) plastic found in oceans ingested by birds, (j) resulted in high algal population in rivers and sea, (k) degrades water and soil quality (Liu et al., 2015). The decomposition of waste into constituent chemicals is a common source of local environmental pollution. This problem is especially acute in developing nations. A major environmental concern is gas release by decomposing garbage (Sankoh et al., 2013). Methane is a by-product of the anaerobic respiration of bacteria, and these bacteria thrive in landfill with high amounts of moisture. Methane concentrations can reach up to 50% of the composition of landfill gas at maximum anaerobic decomposition (Cointreau-Levine, 1997). A second problem with these gasses is their contribution to the enhanced GHGs effect and climate change (Alam and Ahmade (2013)). However recently, in most developed countries, landfills have been designed so that advantage of biogas to generate energy could be maximised by reducing the damaging impact of landfills. But in developing countries like India, landfill structures are still open, not designed properly and might lead to public health hazards. However, increasing resource scarcity and the availability of new technologies are offering opportunities for turning waste to wealth through several technologies, particularly composting (Khalid et al., 2011).

3.2. Effects of MSWC in restoring fertility of salt-affected soils

Sustainable management of salt-affected soil aims toward improved soil physical, chemical and biological properties thereby increasing crop productivity. However, for reclamation of these soils expensive technologies is required particular to sodic soils (chemical amendments) whereas, saline soils can reclaim easily by good quality water and organic amendments with proper and permanent care (Prapagar et al., 2012). Adequate soil and water conservation practices, based on a comprehensive soil or land degradation assessment can provide a timely indication that provides opportunities for efficient salinity/alkalinity control, the prevention of these environmental stresses and their undesirable ecological, economic and social consequences. Concerning the affected soils, a wide array of organic soil amendments, with varying levels of processing and characterization are used for their reclamation. Compost is most frequently used to provide essential nutrients (Lakhdar et al., 2008) to rebuild soil physico-chemical properties, and re-establish microbial populations and activities (Hanay et al., 2004). Addition of MSWC in such soil enriches the rhizosphere with micro- and macro-nutrient elements and counteracts nutrient depletion (Lakhdar et al., 2008). While, Iglesias-Jimenez and Alvarez (1993) found that 21% of the total N in MSWC was available as NH_4NO_3 approximately six months after application. In same way, Weber et al. (2007) reported that continuous release of nitrogen from compost into the soil improves not only the soil fertility, but also the conditions of organic matter mineralization. Hargreaves et al. (2008) stated that compost organic nitrogen mineralization dependent on many factors including C/N ratio of raw material, composting conditions, compost maturity, time of application, and compost quality. As well increased KCl and K_2SO_4 salinities had a stimulating effect on organic matter mineralization (Chandra et al., 2002). Unfortunately, the compost application could promote nitrification process and consequently a possible groundwater contamination (Walker and Bernal, 2008) especially when there are not crops that can take up the mineralized nitrate. However, compared with mineral fertilization, the soil amendment reduces nitrogen leaching, decreasing the possibility of nitrate groundwater contamination (Montemurro et al., 2007). Phosphorus is one of the most essential plant nutrients. The bioavailability of P is strongly tied to soil pH. The pH between 5.5 and 7.0 constitutes the optimum range for P release. In saline soil Muhammad et al. (2007) found an increase of $NaHCO_3$-extractable P following 1% of compost amendment. Presumably while decomposing organic matter releases humic acid, which in turn convert unavailable soil phosphates into available forms. Humus, since it is normally negatively charged, is not thought to retain much P by itself in soils, however, in association with cations provided by amendment such as Fe^{3+}, Al^{3+}, and Ca^{2+}, it is able to retain significant amounts (Wild, 1950). These authors also reported that 1 ton of compost, on an average, contains 50 kg P_2O_5. In addition, MSWC supplies similar amounts of P as inorganic fertilizer (NPK) (Mkhabela and Warman, 2005), nonetheless compost effect remains for long-term (Park et al., 2004). Application of MSWC improves sustainability and crop productivity of salt-affected soil.

3.3. Effects of MSWC on biological properties of salt-affected soils

Recently various organic supplements, such as organic mulches, manures and composts, have been investigated for their efficiency in reclamation of salt-affected soils. Biomass C, N, and S was increased in the soil immediately after compost addition and for up to 1 month, while biomass P showed an increasing trend for 5 months (Perucci, 1990). The importance of microbial biomass of compost amendment turns to the essential role of soil microbe in nutrients cycling ecosystems (Christenen and Johnston 1997). The amendment of saline soil with compost enhances their subsequent mineralization with microflora and concomitant increase in CO_2 release and consequently soil aeration (Muhammad et al., 2007) presumably owing to stimulation in enzymatic activities that lead to break down of complex organic residues into simple sugars and starch; also it causes priming effect. During the microbial degradation and humification of residues, the residual carbon is released to the atmosphere as CO_2 (Islam et al., 2012). However, some authors have reported that microbial activity and microbial biomass were not related to soil salinity or high pH (Luna-Guido et al., 2000).

The incorporation of rice straw, swine excrement or rice straw plus swine excrement significantly increased the activities of urease and phosphatase and the rate of respiration of soil system (Liang et al., 2003), coinciding with previous reports on the incorporation of organic matters in saline soils. However, the excessive use of organic manure should be avoided, especially in areas flooded for long-periods, in order to reduce the risk of toxic effects from reduced intermediates, which accumulate from the anaerobic decomposition of organic manure (Liang et al., 2003). The incorporation of organic matter increased the amount of C mineralization, even at high salinity levels. It also caused a reduction in the negative effect of salinity on microbial activity. Xiaogang et al. (2006) reported the decomposition of SOM under salt stress to the soil water content. In fact a greater amount of CO_2 emission was observed using NaCl or Na_2SO_4 at both 17% (w/w) than 25% (w/w) concentrations of salt. Soil urease and alkaline phosphatase activity, and respiration rate as well as salt tolerance of plants were significantly stimulated by incorporation of organic amendment in rice-barley rotation system (Liang et al., 2003). Incorporation of organic materials influences enzymatic activities in the soil because the added organic fractions may contain intra- and extracellular enzymes (Lakhdar et al., 2008) which stimulate microbial activity in the soil (Goyal et al., 1993). In the same way, microbial metabolic quotient (qCO_2) is used as an indicator of biological activity through estimating the efficiency of microbial biomass to utilize available carbon for biosynthesis (Wardle and Ghani, 1995). After one year of incubation, a sharp increase in qCO_2 in an aridisol amended with an amount of MSW sufficient to raise its organic matter by 1.5% (Pascual et al., 1997).

The general opinion is that microbes living in a stressed environment put up defence mechanisms by increasing their respiration per unit biomass, so increasing $q\text{CO}_2$ (Anderson and Domsch, 1993). Pascual et al. (1999) demonstrated that an eight year amendment of an arid soil with organic fraction of MSW at two different rates (6.5 and 26 ton/ha) had a positive effect on the activity of enzymes involved in the C, N, P cycles as well as on biomass carbon, constituting a suitable technique to restore soil quality due to better supply of substrates and lower heavy metal toxicity. In fact, even if microbial activity is depressed by salts, biochemical mineralization by soil enzymes (amidases and deaminases) could still not be adversely affected at high salinity and alkalinity (Pathak and Rao, 1998). Application of organic amendments to soil stimulates enzyme activities (Liang et al., 2003) due to availability of high quantity substrates added to the affected soil although, the mineralization activity seems to be not affected by salinity (Muhammad et al., 2007). In the same way, Crecchio et al. (2001) observed in a two year experiment that MSWC increased organic C and total N contents, dehydrogenase activity. The activities of such enzymes basically depend on the metabolic state of the soil biota (Garcia-Gil et al., 2000).

Phosphatase is the enzyme responsible P mineralization and P turn over, involved in catalyzing the hydrolysis of both ester and anhydride forms of phosphoric acid in soils (Criquet et al., 2004). According to Tripathi et al. (2007), phosphatase activity responded more to pH than soil salinity, under high pH alkaline form predominates. Ozur et al. (2008) observed obvious increase of this enzyme activity following compost treatment. Since, higher plants are devoid of alkaline phosphatase, the alkaline phosphatase of soils seems to be derived totally from microbes (Juma and Tabatabai, 1998). Microbes can produce and release large amounts of extracellular phosphatase due to their large combined biomass, high metabolic activity and short life cycles (Meena et al., 2016b).

However the combined use of chemical fertilizers and compost accelerated the decrease in the organic P fractions, this can be attributed due to the promotion of microbial activities in the plough layer, even though a high amount of organic P was inputted by compost (Chang Hoon et al., 2004). β-glucosidase is one of the most important glucosidases in soils because it catalyzes the hydrolysis of carbohydrates with δ-glucosidase-bonds, such as cellobiose. As a result, this enzyme contributes to the mineralization of cellulose (Landgraf et al., 2003). Indeed, with time of incubation the early adverse effect of pH on nitrites is relieved due the remedial effect resulting from organic matter decomposition (reduction of pH and ESP). Hence use of MSW improves nutrient cycling enzyme activity and microbial biomass in salt affected soils.

3.4. Effects of MSWC on physico-chemical properties of salt-affected soil

Well known fact that use of compost in salt-affected soils improves soil physical condition as well help in rebuilding fertility of soil (Fig. 3). Integrated and site specific use of MSWC slightly reduced the pH_s, EC_e and SAR compared to the initial status of soil while organic matter, available P, extractable K and Zn was enhanced over the initial values. A slight increase in heavy metals such as Co, Cu and Pb was also observed with the application of MSWC in soil (Sarfraz et al., 2017). Long-term application of MSWC continuously increased soil organic matter and soil C/N ratio to levels greater than those of unamended soils (Walter et al., 2006). Plants are negatively affected by excess salts in soils and Na can be detrimental to soil structure. Increased soil EC values were found to decline over time, perhaps due to leaching and nutrient removal by crops (Zhang et al., 2006). In similar way Meena et al. (2016b) reported that application of MSWC 16 ton/ha had significantly reduced salt concentration and increased biological activities than unfertilized control in a mustard-pearl millet cropping system. Hence, organic amendments may improve soil physical properties for years after application (Ginting et al., 2003), owing to initial degradation of and availability to plants and rhizospheric microbes (Hadas et al., 1996). Chemical fertilizers would keep the SOM pool of 60 million ton/ha in 2050, however compost addition manage to enhance this pool more than double of the conventional tillage system without fertilizer (Table 5). The positive effects of composts on salt-affected soils depend on soil texture, moisture and the origin of organic matter (Drozd, 2003). In sodic soil, Na^+ constitutes a highly dispersive agent resulting directly in the breakup of aggregates (Bronick and Lal, 2005). Exchangeable Na^+ in the soil solution and at the exchange sites contribute to repulsive charges that disperse clays particles (Fig. 2).

The availability of nitrogen in MSWC has been estimated at around 10% in the first year after application (Zhang et al., 2006). Iglesias-Jimenez and Alvarez (1993) noticed that 16–21% of the total N in MSWC was available as NH_4NO_3 after 6 months of application and similarly, Hadas and Portnoy (1997) observed around 22% recovery of total N. Whereas, some studies showed that MSWC increased soil N content. While, MSWC is often reported to be less

Table 5

Physico-chemical characteristics of compost samples collected during different maturity stages of composting process adapted from Shyamala and Belagali (2012).

Parameters	Number of sample days						Recommended standard
	10	20	30	40	50	60	
Moisture (%)	82	85	86	61	42	29	45–65
Particle density (ton/m^3)	2.0	2.0	2.5	1.9	0.70	0.62	0.25
Water holding capacity (%)	16	25	42	51	75	80	NA
pH	8.7	8.8	8.4	7.7	7.4	7.1	6.9–8.3
EC (1:5) mS/cm	2.4	4.0	4.5	5.0	7.2	7.7	2–6
C:N ratio	13.3	10	8.7	7.9	6.6	5.5	< 25
Total organic carbon (%)	16	14	13	13	12	10	NA
Ammonia nitrogen (%)	1.6	0.18	0.21	0.35	4.20	1.60	0.05
Nitrate nitrogen (mg/L)	0.05	0.93	3.2	5.6	6.0	9.0	NA
Total phosphorus (%)	1.43	4.01	5.2	6.3	6.22	13.8	0.4–1.1
Potassium (%)	0.06	0.07	0.08	0.08	0.09	0.13	0.6–1.7
Carbonates (g/L)	20	30	70	200	150	160	NA
Bicarbonates (g/L)	900	990	1170	1400	1500	1510	NA
Calcium (%)	9.5	12	14	16	17	61	1–4
Magnesium (%)	0.99	1.5	3.1	4.7	9.1	11	0.2–0.4
Sodium (%)	0.02	0.03	0.03	0.03	0.35	0.08	NA
Soluble sulphate (%)	16	21	46	50	55	61	NA

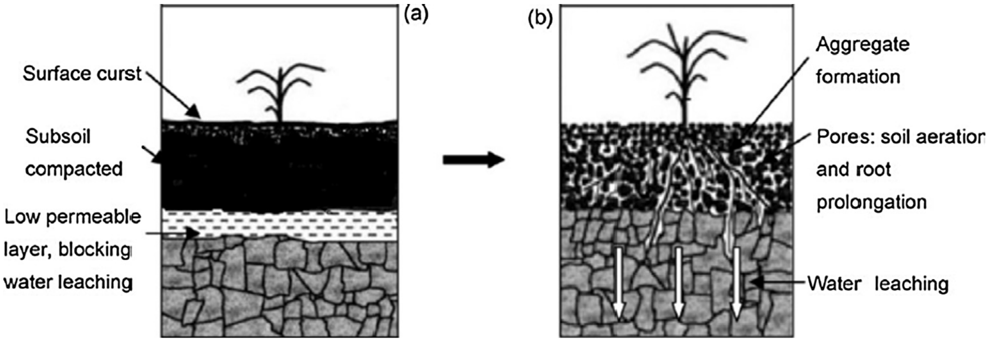

Fig. 2. Schematic representation of the soil before (a) and after (b) organic amendment addition (). Adapted from Lakhdar et al. 2009

effective in supplying available N in the first year of application to the soil-plant system than inorganic mineral fertilizers. Pathak and Rao (1998) reported that stimulus of N mineralization in the salt-affected soil due to increase in solubilization of SOM at high pH, which provides increased amount of carbonaceous substrates for microbial growth. Weber et al. (2007) reported that continuous release of nitrogen from compost into the soil improves not only the soil fertility but also the conditions of organic matter mineralization. As well increased in KCl and K_2SO_4 salinity had a stimulating effect on organic matter mineralization (Chandra et al., 2002). Unfortunately, the compost application could promote nitrification process and thereby a possible groundwater contamination (Walker and Bernal, 2008), especially in fallow condition. Compared with mineral fertilizer, the soil amendment reduces nitrogen leaching, decreasing the possibility of nitrate groundwater contamination (Montemurro et al., 2007).

Hu and Schmidhalter (2005) highlighted, the uptake of P by crops is reduced in dry-soil conditions and the availability of this macronutrient can be reduced in saline soils. Conversely, during mineralization process, organic matter releases humic substances, which may convert soil phosphates into available forms, thus improving P release from hardly soluble rock minerals due to high total acidity. MSWC has been reported to effectively supply P to soil with soil P concentration increasing with increasing application rates (Zhang et al., 2006). Salinity and sodicity can affect forms and dynamics of this nutrient in soil (Dominguez et al., 2001). The bioavailability of P is strongly tied with soil pH (Hopkins and Ellsworth, 2005). Additionally, under saline soils the available fraction of K can increase through the increase of CEC linked to organic matter content. In particular, application of poultry manure and compost to soil can increase both the CEC and soluble and exchangeable K^+, which is a competitor of Na^+ under sodicity condition, thus, limiting the entry of Na^+ into the exchange complex (Wang et al., 2014). Moreover, K^+ is important to maintain the turgor pressure of plant under drought and salinity stress. In saline soil Muhammad et al. (2007) found an increase of $NaHCO_3$-extractable P following 1% application of compost. Presumably while decomposing organic matter releases humic acid, which in turn convert unavailable soil phosphates into available forms. Such being the case, compost or other organic if applied with high-grade phosphate minerals must work as very effective phosphate fertilizers (Sekhar and Aery, 2001) 10–50% of total P in MSWC was available both the first and second year after application (Soumare et al., 2003). Plant uptake of P was increased with the addition of MSWC further uptake was increased with application rate. Humus, since it is normally negatively charged, is not thought to retain much P by itself in soils, however, in association with cation provided by amendment such as Fe^{3+}, Al^{3+}, and Ca^{2+}, it is able to retain significant amounts of P (Wild, 1950). Frossard et al. (2002) observed that composted organic solid wastes contained between 2 and 16% of their total phosphorus as rapidly exchangeable inorganic phosphorus, between around 40 and 77% of their total phosphorus as slowly exchangeable.

A long-term study of MSWC demonstrated that K was available in MSWC as in mineral fertilizers. About 36 to 48% of total K in MSWC was found to be plant available (Soumare et al., 2003). Soil K concentrations are increased even when very low rates of MSW are used (Giusquiani et al., 1988). Moreover, organic matter plays an important role in determining K dynamics in soils, as organic colloids possess negative charges that arise from the dissociation of carboxylic and phenolic groups during organic matter decomposition (Bhattacharyya et al., 2007). Under saline soil, mineralization of compost increase plant available K fraction through increase in CEC (Walker and Bernal, 2008). In addition, the high content of non-exchangeable fraction indicated that the organic matter could supply available K^+ and increase the K^+/Na^+ selectivity ratio in plant (Liang et al., 2003). The enrichment of the exchange complex with Ca^{2+} and Mg^{2+} as reported by Walker and Bernal (2008) could be beneficial in the reclamation of saline-sodic soils, since it could decrease the proportion of Na^+ in the exchange complex, finally improved soil physical properties. However, quantity of

Fig. 3. Role of MSW in the restoration of degraded soil sustainability.

macro- and micro nutrients in compost products depends on the feedstock's type and origin and the method of compost production. Their availability is also controlled by mineralization or compost decomposition rate.

Selected studies (from literature of the last 10–15 years) are summarized in table 6, focusing on the effects of application of different organic waste materials on chemical, biological, and physical soil properties under soil salinity conditions. It was observed that, most of the nutrients and metal ions were decreasing in the later stages of composting, which is due to leaching of ions with the water present in the solid waste. This can be reduced by collecting the leachate and spraying it on the composting pile. It also enhances the degradation process since leachate is rich for microorganisms. Iron content was higher in post- monsoon season and least in pre-monsoon season. Lead, chromium and nickel were lower in monsoon season. Manganese, lead and nickel concentrations were high during pre-monsoon, whereas iron and manganese concentrations were high during post monsoon season. The composting samples of monsoon season were rich in essential plant nutrients, contain lesser amount of heavy metals and hence it can be considered as good fertilizer. Excess of heavy metals in compost enhances the toxicity of soil. Lime is very effective amendment material for heavy metal immobilization in compost with sewage sludge (Wong and Selvam, 2006). Addition of lime caused a significant reduction in water-soluble Cu, Mn and Zn contents during composting process. The pH was considered 'master variable' controlling ion exchange, reduction/oxidation, adsorption and complexation reactions. Cations are adsorbed on organic matter at high pH. The effect of organic matter amendments on heavy metal solubility also depend greatly upon the degree of humification of their organic matter and their effect upon soil pH. The reported findings showed that application of organic fertilizers plays an important role in improving the soil properties in salt stressed soils. Diacono and Montemurro (2015) identified organic materials (e.g., farmyard manures, different agro-industrial by products, and composts) as effective tools to improve different soil properties (e.g., structural stability and permeability) in salt-affected soils. Overall, MSW application has beneficial effect on soil structure, aggregation, water holding capacity, nutrient availability and nutrient supplying capacity.

3.5. Effect of MSWC on crops yield in salt-affected soils

With application of MSWC in saline conditions, crop yield was significantly improved than control. Meena et al. (2016b) reported that application of MSWC 16 ton/ha had significantly higher grain yield of mustard and pearl millet than control (Table 7). Significantly higher yield of crops with organic amendments was possibly due to beneficial effects on microbial activities and better supply of balanced plant nutrients, which are not supplied by inorganic fertilizers alone (Yadav et al., 2000). MSWC improved soil physical properties; it might also have contributed to the improvement in crop yields. Similar results of improved soil physical properties from addition of organic amendments (Gopinath et al., 2008).

Table 6
Heavy metal concentrations during different maturity stages of composting process adapted from Manohara and Belagali (2014).

Name of parameters	Number of sample days						Recommended standard
	10	20	30	40	50	60	
Copper (ppm)	410	350	370	320	290	250	1500
Zinc (ppm)	670	300	680	650	670	630	700–1850
Iron (g/kg)	6.8	5.3	4.5	3.0	1.8	1.05	NA
Manganese (ppm)	40	22	35	41	28	33	5–200
Lead (ppm)	30	51	48	45	42	34	150–500
Chromium (ppm)	83	87	71	66	63	50	210
Nickel (ppm)	33	31	26	25	25	22	62–180

Table 7
Effects of MSW compost on soil properties and crops productivity discussed.

MSWC (ton/ha)	Crops	Experimental conditions	Comments	References
16.0	Mustard-pearl millet	Field experiment	Yield was significantly increased over control	Meena et al. (2016a)
0.03, 0.06 and 0.12	Wheat	Pot experiment	Increase yield, downward movement of P observed	Bar-Tal et al. (2004)
5.9–6 and 40	Rice	Pot and field experiments	Increased yield, pH, high rates did not affect microbiology of soil	Bhattacharyya et al. (2003)
20 and 80	Barley	Filed experiment	Increased microbial metabolism in soil; long-term increased buffering capacity of soil	Garcia-Gil et al. (2000)
15, 30, and 60	N/A	Pot experiment	Increased water holding capacity, pH, soil Zn and Cu concentrations	Hernando et al. (1989)
10, 20, 30, 40, and 50	Ryegrass	Pot experiment	High rates can provide sufficient N for ryegrass, EC increased with rate, soil P retention decreased	Iglesias-Jimenez and Alvarez (1993)
15, 30, and 60	N/A	Pot experiment	Increased water holding capacity, pH, soil Zn and Cu concentrations	Hernando et al. (1989)
10, 20, 30, 40, and 50	Ryegrass	Pot experiment	High rates can provide sufficient N for ryegrass, EC increased with rate, soil P retention decreased	Iglesias-Jimenez and Alvarez (1993)
40.0	Barley	Field experiment	Significantly increased in carbon, nitrogen and potassium under both non-saline and saline conditions	Lakhdar et al. (2011)
90 and 270	Corn	Field experiment	Composts highly variable year to year	Mamo et al. (1999)
Alfalfa-150; Cocksfoot-60	Alfalfa-cocksfoot	Field experiment	Organic carbon increased	Montemurro et al. (2006)
100 (2 applications)	Clover	Pot experiment	Increased N, Zn, Cu, Ni, and Cr uptake	Murillo and Cabrera (1997)
35, 70, and 140	Tomatoes	Field experiment	Increased soil concentrations of Cd, Cu, Pb, Ni, and Zn, fruit uptake was not observed	Ozores-Hampton and Hanlon (1997)

3.6. Effects of MSWC on heavy metal accumulation in soils

It is obvious that application of MSWC improves the productive potential of salt-affected soils. These wastes may cause to some negative effects on the agricultural soils due to their metal toxicity (Lakhdar et al., 2008). The majority of the agricultural soils are poor in organic matter. Net accumulation of the organic matter in the soil is a function of the rate and frequency of amendments added and of agriculture residues returned to the soils. The farmyard manure which was usually used in agriculture in order to restore the SOM becomes more and more rare and expensive. However, MSWC presents an interesting alternative; indeed, it constitutes an important organic mass for the formation of steady humus (Tidsell and Breslin, 1995). While, long-term application of compost can accumulate heavy metals in soils (Kidd et al., 2007). These elements can be assimilated by plants, and thus contaminate the food chain and threaten human health (Jordao et al., 2006). They could hamper the use of MSWC in agriculture. The concentration of heavy metals in MSWC is related to the quality and the original composition of the waste materials used for composting, site characteristics and techniques applied for composting (Smith, 1992).

Therefore, it is an important to optimize the doses of MSWC and type of feed stock for composting. Depending on feedstock, certain composts have been shown to contain elevated concentrations of metals including Pb, Cd, Cu, and Zn (Van-Camp et al., 2003). Feed stocks which contribute organic pollutants included pesticides, household wastes such as oils and solvents, and paper products (Epstein, 1997). The chemicals that have been recognized as problems in amendment derived sewage sludge include heavy metals, polycyclic aromatic hydrocarbons (PAHs), polychlorinated biphenyls (PCBs), and dioxins and furans (PCDD/Fs) (Harrison et al., 2006). Surfactants and some of their metabolites are not readily biodegraded in non-aerated environments and may cause adverse environmental impacts when the sewage systems in high loads and accumulate in sludge (During and Gath, 2002). It was reported that MSWC under 0.5% by weight is hazardous and researchers indicated that phthalate esters are likely the most abundant xenobiotic present in MSWC (Logan et al., 1999). Furthermore, the use of immature composts can cause phytotoxic effects, as well as nutrients deficiency and reduction in crop yield (Bernal et al., 1999). Policy framework for MSWC in future prospective has been displayed in Fig. 4. Conclusively, even though MSW improves soil physico-chemical properties, biological resilience and crop yield, rate and time of application needs special care to minimise the heavy metal toxicity.

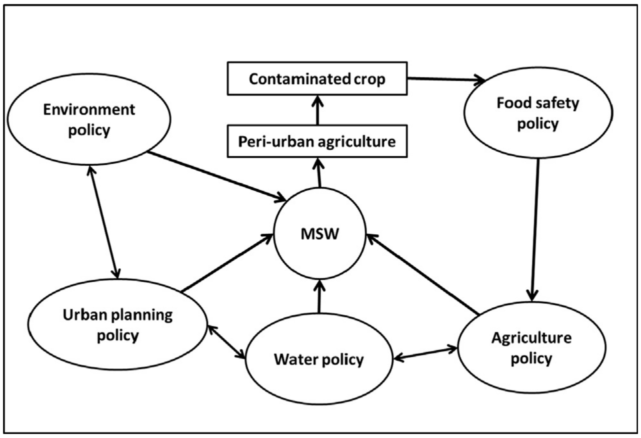

Fig. 4. A policy frame-work for MSW in future prospective.

4. Compost quality parameters

At present time, a number of criteria and parameters have been proposed for monitoring the composting process and evaluating the stability of the compost. The term stability and/or maturity are commonly used to define the degree of decomposition of organic matter during the composting process even if they are conceptually different. Maturity parameters are based on different properties: physical, chemical and biological, including microbial activity (Bernal et al., 2009). Some of the methods that have been used to measure maturity include C/N ratio, changes in nitrogen species, pH, EC, CEC, organic chemical constituents, reactive carbon, humification parameters, temperature, color, odor, structure, specific gravity, plant assays, respiration, microbial population changes, enzyme activity germination tests, and colorimetric and spectroscopic methods (Bazrafshan et al., 2016). Unfortunately, all of these tests are only suitable for specific types of compost and are inadequate parameters for assessing compost maturity. The principal requirement of compost for it to be safely used in soil is a high degree of stability or maturity, which implies stable organic matter content as well as the absence of phytotoxic compounds and plant or animal pathogens.

Compost maturity refers to the degree of decomposition of phytotoxic organic substances produced during the active composting stage (Wu et al., 2000). The application of immature compost results in inhibition of seed germination, root destruction, and suppressed plant growth. Composting is basically as biodegradable of waste materials occurring in favorable conditions (good aeration, temperature, moisture, etc.) and allowed to transform the raw materials probably unsanitary or with phytotoxic properties to a stable and mature end product (Amir et al., 2005). As it has been shown that incorporation of this amendment improves salt-affected soil in the presence of good compost quality. The periodical changes in MSWC are given in table 8. Heavy metal concentration in biosolids produced in different countries may differ due to dissimilar wastewater treatment technologies adopted or because of variation in generated wastewater‘s chemical composition and also sources of waste water Maximum allowable concentrations for heavy metals in biosolids from different countries is are also different. A prime reason for heavy metal contamination in biosolids is unplanned or mismanaged urban sewerage system that leads to mixing of sewage with industrial wastewater (Healy et al., 2016) and also from commercial sources, storm water runoff from city roads etc. Toxic substances like several organic micropollutants such as pesticides, insecticides, disinfectants, pharmaceuticals, detergents, personal care products, steroid hormones and various other inorganic salts are present in wastewater and finally in the processed biosolids. Attempts for commercial production of biosolids based fertilizer and soil health amendments can be setup and can be used to boost agricultural production, and minimizing the dependency on inorganic fertilization (Sharma et al., 2017). However, various parameters to evaluate compost quality are very complex and depend on the original organic matter. While, general parameters for judging the compost qualities are:

4.1. Carbon (C) to nitrogen (N) ratio (C/N)

The C/N ratio represents the single most and very good index of maturity for the organic substance, as it significantly affects the microbiological growth. The C/N ratio narrows down gradually as the composting progresses because of the conversion of organic carbon to carbon dioxide (Moharana and Biswas, 2016). The total organic C in compost includes forms of organic matter at different stages of degradation, some resistant to further decomposition and

Table 8
Comparison of the physico-chemical properties of biosolids of different countries.

Properties	India#	China*	Australia$	Spain@
pH	6.16–7.50	6.86–8.73	4.40–8.30	7.10–8.10
EC (mS/cm)	2.28–2.70	0.667–5.01	1.60–7.90	1.20–3.90
Organic C (%)	5.52–12.60	–	–	–
Total N (%)	1.60–1.73	2.23–6.50	0.60–2.50	3.0–4.10
Total P (%)	0.49–1.30	1.06–2.18	0.28–0.83	2.0–3.60
Available P (mg/kg)	132–716.70	–	–	13,900
Total K (%)	0.8–1.26	0.16–0.62	0.18–0.45	0.24–0.47
Exchangeable K (mg/kg)	208.9	593	–	–
Exchangeable Na (mg/kg)	483	–	–	–
Exchangeable Ca (mg/kg)	154.1	–	–	–
Total metals				
Fe (mg/kg)	6059–14,390	0.46–2.40	13,824–18,026	31,200
Ni (mg/kg)	47.17–60	52.5–202	166	< 25–71
Mn (mg/kg)	186.2–260	0.35–537	173	165–233
Zn (mg/kg)	161–2050	0.21–1350	210–3060	560–1100
Pb (mg/kg)	28.5–240	49.1–186	323	43–219
Cr (mg/kg)	35.5–60	52.8–288	308	1–210
Cd (mg/kg)	32.3–154.5	2.23–7.60	0.70–13.6	< 0.2–3.0
Cu (mg/kg)	186–330	0.27–975	92–1996	149–230

Data source: #Latare et al. (2014); #Singh and Agrawal (2010); #Walia and Goyal (2010); *Xue and Huang (2013); *Cai et al. (2010); *Cheng et al. (2007); *Wei and Liu (2005); *Wong et al. (2001); $Nash et al. (2011); $Merrington et al. (2003); $Joshua et al. (1998); @Garcia-Gil et al. 2000; @Antolín et al. (2005); @Roca-Perez et al. (2009); @Fernandez et al. (2009); @Marguí et al. (2016)

some remaining biologically active. Hue and Liu (1995) also proposed a value of Water Soluble Carbon (WSC)/Org-N ratio < 0.70 as an index to judge the maturity of compost, whereas, Bernal et al. (2009) proposed a value of WSC/Org-N < 0.55 to describe well-matured and stabilized compost.

4.2. Nitrification index (NI)

Compost maturity can also be defined in terms of nitrification. The ratio of NH_4^+ -N to NO_3^- -N is called as the nitrification index (NI) which can be used as an indicator of compost maturity. Bernal et al. (2009) reported that NI decreased during the composting process, the values obtained were well > 0.16, the maximum ratio as suggested by for mature compost.

4.3. Humification and E4/E6 ratio

Humification during composting of organic substrates is considered another important indicator of compost maturity as it results in the decomposition of non-humic substances and formation of humic substances (Tiquia, 2005). Therefore, humic acid fraction generally increases during composting, demonstrating the humification of organic matter. Humic acid comprises of mixture of weak aliphatic (carbon chains) and aromatic (carbon rings) organic acids which are not soluble in water under acid conditions but are soluble in water under alkaline conditions. Humic acids consist of that fraction of humic substances that are precipitated from aqueous solution when the pH is decreased < 2. The E4/E6 ratio is the ratio of optical density of humic acid solutions at 465 and 665 nm, respectively. This ratio is considered as an inverse index of particle size, aromaticity and less value means more stability of composts. The value of E4/E6 ratio greater than 1.7% has been considered as the threshold value for the maturity of that particular mixture (Iglesias-Jimenez and Perez Garcia, 1992).

4.4. Total soluble salts and pH

Total soluble salts (also expressed as electrical conductivity) it is a measure of water soluble salts (or salinity) present in compost or soil to which plant roots will be exposed. The recommended range of EC in compost is < 2.5 mS/cm (1:1 soil to water) (Leaon, 1995). However, application of compost on such affected soil helps to diminish salinity thereby improving soil characteristics, mainly by the increase of salts leaching.

The pH ranging from 6.7 to 9.0 supports good microbial activity during composting. Optimum values are between 5.5 and 8.0 (Miller, 1992). The pH value is very relevant to control N-losses by ammonia volatilisation, which can be particularly high at pH > 7.5. Elemental sulphur (S) has been used as an amendment for avoiding excessively high pH values during composting (Mari et al., 2005).

4.5. Cation exchange capacity (CEC)

The addition of compost can increase the soil CEC from 20 to 70% of the original CEC. However it depends of the compost pH, thus care should be taken when comparing the CEC of composts with different pH. The CEC is the most important chemical parameter to check the stability and maturity of the compost. The higher value of CEC at the end of composting process give the more mature compost without any phytotoxicity and increased germination index (Ameen et al., 2016). Addition of compost can increase the soil CEC from 20 to 70% of the original CEC because of its higher CEC and water holding capacities as well as its chelation ability thereby influence soil stability (Meena and Biswas, 2014). However, it depends on the pH of compost, thus care should be taken when comparing the CEC of composts with different pH.

4.6. Aeration, Moisture, porosity and bulk density

Aeration is a key factor for composting. Proper aeration controls the temperature, removes excess moisture and CO_2 and provides O_2 for the biological processes. The optimum O_2 concentration is between 15 and 20% (Miller, 1992). Controlled aeration should maintain temperatures below 60–65 °C, which ensures enough O_2 is supplied (Finstein and Miller, 1985). The optimum water content for composting varies with the waste to be composted, but generally the mixture should have 50–60% water (Gajalakshmi and Abbasi, 2008). When the moisture content exceeds 60%, O_2 movement is inhibited and the process tends to become anaerobic (Das and Keener, 1997). During composting a large quantity of water can evaporate, to control temperature, and as water content diminishes the rate of decomposition decreases, then rewetting should be required in order to maintain the optimum moisture content for the microbial activity.

Porosity greater than 50% causes the pile to remain at a low temperature because energy lost exceeds heat produced. Too little porosity leads to anaerobic conditions and odour generation. The percentage air-filled pore space of composting piles should be in the range of 35 to 50%. Compost amendment reduces saline soil bulk density through increasing aggregation. The range of bulk density of MSWC reported by He et al. (1995) is between 0.22 and 0.74 ton/m^3.

4.7. Temperature

The temperature pattern shows the microbial activity and the occurrence of the composting process. The optimum temperature range for composting is 40 to 65 °C (de Bertoldi et al., 1983) temperatures more than 55 °C are required to kill pathogenic microbes. But if the temperature achieved exceeds the tolerance range of the thermophilic decomposers, the effect is damaging for composting. At temperatures more than 63 °C, microbial activity declines rapidly as the optimum for various thermophiles is surpassed, with activity approaching low values at 72 °C. The range of 52–60 °C is the most favourable for decomposition (Miller, 1992).

4.8. Total nutrients concentration

Nutrient contents of compost are often moderate but vary among sources due to differences in waste materials and processing methods. To report compost as having fertilizing capabilities and it to be used in agriculture total nitrogen (TN) content must be over 1% DW (dry weight) (Barker,1997). If compost contains TN<1%, supplemental nitrogen fertilizer will be required if the compost is to be used as a soil improver. The typical range of TN in compost is 1.0–3.0% DW. Compost over 3% TN is usually found to be immature and ammoniacal (Barker, 1997). The decomposition of organic matter release gradually plant available phosphorus. The range of phosphorus that has been found in MSWC is between 5 and 35 g/kg DW (Hargreaves et al., 2008). The availability is closely related to soil pH (5.5 and 7.0), while, the suggested P concentration in soil solution should be above 0.2 mg/L to meet the needs of the crop (Chen et al., 2001). Concerning potassium, typical range of total content is between 0.6 and 1.7% DW and the typical range of available potassium in this compost is between around 620 and 2280 mg/L, fresh weight. Compost contain calcium and magnesium which act as bases when they exist as oxides, hydroxides and carbonates when applied to soil, and may counteract soil acidification and vary pH levels making soil nutrients more available to plants (Fricke and Vogtmann, 1994). As a consequence of increased Ca^{2+} concentration in soil solution, Na^{+}-Ca^{2+} exchange at the soil's cation exchange sites, leaching of the exchanged Na^{+} in percolating water and subsequent reduction in soil sodicity (Qadir and Oster, 2004). The typical range of calcium in compost is between 1.0 and 4.0% DW and the typical range of magnesium is 0.2–0.4%, dry weight.

4.9. Rhizospheric microorganisms

The SOM decomposition is carried out by many different groups of microbial populations (Ryckeboer et al., 2003). The microorganisms involved in composting develop according to the temperature of the mass, which defines the different steps of the process (Keener et al., 2000). Bacteria predominate early in composting; fungi are present during all the process but predominate at water levels below 35% and are not active at temperatures more than 60 °C. Actinomycetes predominate during stabilisation and curing, and together with fungi are able to degrade resistant polymers. Particle size and distribution are critical for balancing the surface area for growth of microorganisms and the maintenance of adequate porosity for aeration. The larger the particle size, the lower the surface area to mass ratio. So compost with large particles does not decompose adequately because the interior of the particles has difficult accessibility for the microorganisms, as during decomposition particles may coat the surface with an impenetrable humified layer (Bernal et al., 1993). However, particles which are too small can compact the mass, reducing the porosity. These factors are material specific: particle size and distribution, shape, packing and moisture content control the porosity of the composting mass.

4.10. Phytotoxicity evaluation

The phytotoxicity of compost extracts was evaluated by the seed germination technique. Seeds were placed on sterile filter paper soaked with 2 mL of compost: water (1:10, w/v) extract for 48 to 72 h in the dark at 27 °C. Number of seeds germinated on the filter paper in petridish was recorded and root length was measured. Seeds germinated in distilled water served as control (Zucconi et al., 1981). The relative seed germination (SG), relative root elongation (RE) and germination index (GI) were calculated as follows:

$$SG(\%) = \frac{A}{B} \times 100 \tag{1}$$

$$RE(\%) = \frac{C}{D} \times 100 \tag{2}$$

$$GI(\%) =) \frac{SG(\%) \times RE(\%)}{100} \tag{3}$$

where, A, B, C, D stands for number of seeds germinated in extract, number of seeds germinated in control, mean root length in extract and mean root length in control.

Based on GI values of composts, Aggelis et al. (2002) proposed the following categories for characterizing composts. If the GI value is<25, the substrate is characterized as very phytotoxic; if GI value is 26 < GI < 65, then the substrate is characterized as phytotoxic; if GI value is 66 < GI < 100, then the substrate is characterized as non-phytotoxic, stable and can be used in agricultural purpose; and if GI more than 101 the substrate is characterized as phytonutrient-phyto stimulant and can be used in agricultural purposes as fertilizer.

The inhibitory effect on germination by the organic fraction of different urban wastes was studied in Murcia, Spain in two experiments using barley (*Hordeum oulgare* L cv Reinete) seeds in petri dishes and ryegrass (*Lolium perenne* L cv Argo) seeds in containers in calcareous soil. Fresh sewage sludge almost totally inhibited germination of barley seeds when used as substrate; fresh municipal solid waste also inhibited germination, although to a lesser degree. Both inhibitory effects were less pronounced when the products had been composted previously. Similar results were obtained when the experiments were carried out with water extracts although overall inhibition was less (García et al., 1992).

In barley crops, rate of germination and root length elongation were higher in mature compost and correlated well with water soluble C negatively. GI being sensitive to phytotoxic conditions, persistence of such condition reduces germination. Several authors have demonstrated that GI increases with composting time due to reduction in phytotoxins in presence of adequate temperature, humidity, oxygen and nutrients (Gariglio et al., 2002). A highly negative correlation between GI and ECe has been also reported (Campitelli and Ceppi, 2008).

5. Conclusions

On the basis of above discussion it can be concluded that application of MSWC in salt-affected soils improves soil sustainability. The MSWC significantly improve crop yields and microbial activities due to freely available energy source in soil. However, continuous injudicious and large use of MSWC in salt affected soil can led accumulation of heavy metal in soil. MSW compost addition on this degraded soil recovered plant growth, raised residue decomposition, and improved physical and chemical properties. Organic wastes increase the OM content of soil, thus its water holding capacity, porosity, infiltration capacity, hydraulic conductivity, and water stable aggregation and reduce bulk density and surface crusting. They also provide essential plant nutrients and maintain soil fertility and thus stimulate crop growth and yield. By increasing microbial activity, the organic manures enhance enzyme activities, microbial respiration and thus increase nutrient availability for agricultural crops. Moreover, they also reduce toxicity of some heavy metals such as Cd and Cr. It may be concluded that organic wastes from different sources can be used for improving soil health (properties) and stimulating plant growth and yield. On the other hand, organic wastes have also some detrimental impacts on soil. With the high manure application dose, surface crusting and decrease in soil hydraulic conductivity may occur. In addition, Na^+ release aggravates soil salinity; sometimes harmful heavy metals may be released. Therefore, it is necessary to determine the proper application doses of these organic by-products to avoid the negative impacts on soil, environment as well as human health. Although the metal contents in the soil after MSWC application are not generally high enough to classify the soil as polluted, a greater effort should be made to separate wastes when they are collected to reduce metal content in the final compost, thus minimising the risks of soil pollution.

The MSWC has potential as a beneficial recycling tool. Its safe use in agriculture, however, depends on the production of good quality compost, specifically, compost that is mature and sufficiently low in metals and salt content. The best method of reducing metal content and improving the quality of MSWC is early source separation, perhaps requiring separation to occur before or at curb side collection. Sewage sludge should not be added to the compost at any point since it will raise the metal content of the compost. The only sources of these metals in source-separated MSWC are plant materials, animal plasma, paper, and food remains, so their concentrations in compost should remain below guideline limits. Bioavailability should be addressed in the guideline limits, in addition to metal loading. For agriculture, complete examination of metal bioavailability in soils exhibiting a range of the factors affecting plant uptake like pH, cation exchange capacity, organic matter content, soil structure, and soil texture is necessary. Research in this area would also have to consider, and account for, the effects MSWC may have on the soil such as, increased soil pH and organic matter content. A fraction of the added organic matter is resistant to decomposition but some of the humic substances eventually decompose releasing metals bound in this fraction. Rather, it is thought that the inorganic residues such as the phosphates, silicates, Fe, Al, and Mn oxide most likely provide long-term retention of metals demonstrating the need for long-term experiments. Therefore, it may be unwise to deem metals bound in the organic matter of MSWC as unavailable for plant uptake. A variety of plant species should also be used in trials in order to identify metal bio-accumulators to ensure that plants are safe for human consumption. Furthermore, metal uptake of edible portions of crops, where the leaf is not the edible portion, should also be measured rather than leaf metal concentrations to estimate potential toxicity. Analytical procedures used to determine metal bioavailability also require attention. It is essential to identify extractants for metals that positively correlate with plant uptake of metals if metal bioavailability is to be considered in guidelines. Field studies seem to represent realistic plant-soil systems taking into account climatic factors, while greenhouse studies are generally more thorough in terms of soil and compost mixing and root exposure, but tend to overestimate metal bioavailability. Optimization of the compost production parameters that increase nutrient availability, specifically nitrogen, need to be identified and widely used in MSW composting. Feedstock selection, aeration, and maturity are some parameters, which have been identified to influence the N content of MSWC. The physical and chemical makeup of MSWC tends to shift with time and source and thus careful yearly monitoring of MSWC quality is required. To be addressed is the standard method to determine bioavailability of nutrients, metals, and trace elements in the compost and a measure of organic pollutants such as polychlorinated biphenyls that may remain in the product. Year to year variation in the properties of compost from the same source prevents researchers from drawing conclusions and inhibits research and effective use of the material. Researchers and individuals using MSWC must be assured that they are receiving a quality product consistently. Implementation of these recommendations could reduce opposition to the agricultural use of MSWC and encourage farmers, municipalities, landscapers, and gardeners to use the product. There is a need to conduct long-term experiments to study the effects of MSWC in improving the physical, chemical and biological properties in salt affected soils. However, organic amendments do not completely overcome the adverse effect of salt but continuous use of compost improves chemical and biological properties of saline soils.

Acknowledgment

The authors are thankful to ICAR-Central Soil Salinity Research Institute, Karnal, Haryana, India and ICAR- Directorate of Rapeseed-Mustard Research, Sewar, Bharatpur, Rajasthan for their valuable guidance, suggestions and facilities provided for preparing this manuscript. We also thankful to Editor-in-Chief, Waste Management and anonymous reviewers for their constructive comments, which helped us to improve the manuscript

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